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An Overview of the Modular Effectiveness/Vulnerability Assessment (MEVA) Architecture

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ABSTRACT

The Modular Effectiveness Vulnerability Assessment - Ground Fixed (MEVA-GF) is an engineering tool for assessing the vulnerability of fixed ground targets to conventional weapon attack. MEVA-GF is a graphical user interface (GUI) based program that provides an architecture for assembling an assessment model or simulation in modular fashion. Individual modules representing the weapon, target, weapon delivery, penetration, blast, fragmentation, etc. are linked together using a data flow paradigm that creates the assessment network. The modularity inherent in the architecture provides the user flexibility in the design of networks by offering modules with varying levels of fidelity. MEVA-GF may be used to configure a fast running stochastic model for Monte-Carlo type calculations that require hundreds of runs for statistical accuracy. Higher fidelity models may be constructed for more deterministic type studies where longer run times are not a consideration and more precision is desired. Critical components within targets may be modeled and assigned to fault trees providing a means for assessing functional damage to a target. The targets response (i.e. damage) to the weapon effects (i.e. penetration, blast, fragmentation) is output into data files and can be visualized using a three dimensional graphical representation.

INTRODUCTION

The Air Force Research Laboratory, Munitions Directorate, Lethality Vulnerability Branch has the mission to develop and maintain models and simulations for assessing the lethality of existing inventory conventional weapon systems and concept weapons against the ground fixed target set. Included in this target set are underground hardened bunkers as well as above ground buildings. Parametric studies using Monte Carlo type stochastic analyses are required for determining the sensitivity of varied weapon delivery options to specific target configurations. The probability of kill statistics provided by the analysis are important for weaponeering and deliberate attack planning. Accurate predictions of a weapon's effectiveness against specific target types is key to this planning process.

The decline in the Defense Research and Development budget has provided the impetus for exploring new weapon concepts with the aid of modeling and simulations. While computational intensive hydrocodes are critical to the weapon design and development process, faster running engineering tools still have a niche to fill. Engineering tools based on physics models and empirical data provide decision makers with estimates of a weapon systems performance against the entire target system. Key critical components such as power systems, computer equipment, etc. are modeled within the target. These critical components are assigned to fault trees in a fashion that allow for predictions to be made for a functional defeat of the target. Cost performance studies can be conducted to analyze the benefit of the new weapon concept over existing inventory weapons for specific applications.

The Modular Effectiveness Vulnerability Assessment - Ground Fixed (MEVA-GF)[1] is an engineering tool for assessing the vulnerability of below ground hardened and above ground targets to attack by existing conventional weapons and concept weapon systems. The MEVA-GF architecture is a graphical user interface (GUI) based program that allows the user to assemble an assessment model or simulation in a modular fashion. Modules that represent the weapon, weapon delivery, weapon effects (i.e. penetration, blast, fragmentation, etc.), and target are linked together in the GUI environment to create an assessment model. Assessment models for parametric studies can be created with lower fidelity, faster running weapon effects modules where hundreds of iterations are required for statistical accuracy. Higher fidelity weapon effects modules may be selected when fewer iterations are to be performed and greater precision is desired. This paper describes the capabilities of the MEVA-GF software version currently under configuration management as well as planned improvements.

MEVA-GF Architecture

The MEVA-GF architecture is based on a data flow paradigm. Independent programs called modules define the weapon/target parameters and calculate weapon effects such as penetration. Within the data flow paradigm, each module executes in turn passing information to subsequent modules. A special Iterator module provides end-to-end control of the simulation using Monte Carlo type iterations.

Figure 1 shows an example MEVA-GF computational network for a weapon penetrating through a target.

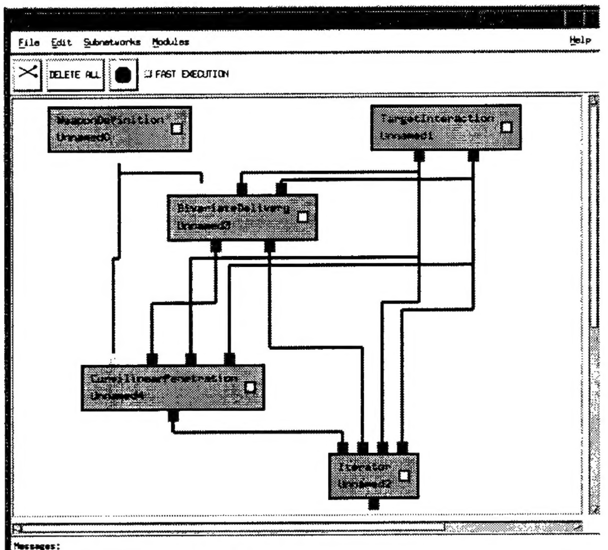

Figure 1. Example MEVA-GF computational network.

The target interaction module at the top right provides the representation of the target and its damage states. The weapon definition module at top left allows the user to define the weapons used during the analysis. The bivariate delivery module determines the impact conditions between the weapon and the target. The curvilinear penetration subnetwork provides a physics based penetration capability through concrete and soil targets. A Monte Carlo Iterator module at the bottom of the network provides end-to-end control of the simulation over entire weapons, sorties, and iterations.

Target Modeling

The BRL-CAD package[2] is currently the only tool for constructing realistic below-ground target models. The user constructs the target using the BRL-CAD model editor, MGED. The type of material associated with each structural component is defined in BRL-CAD. The properties of each material type are specified in an accompanying ASCII formatted material table. Although the resulting target model includes geometric data about structural components, it does not include engineering data about their connectivity. The target files generated by BRL-CAD are read by the MEVA-GF Target Interaction module.

The Target Model Generator (TMG) module builds BRL-CAD-formatted above-ground targets based on limited user-input data. Users enter overall height, width, depth, building function, and construction type. The TMG output format is a mix of ASCII and BRL-CAD formatted output files. These files contain geometry and engineering data about the building components (i.e. walls, floors, columns, and beams). The engineering data contains material properties and connection properties for the structural components. The Target Model Generator can automatically build steel-framed, light-clad office and masonry buildings. Uncertainty in target geometry due to limited intelligence data is captured by assembling multiple buildings of a single configuration, but with varying dimensions.

A Smart Target Model Generator (STMG) is currently under development. The objective of the STMG is to create a standard target description language that serves target information to a spectrum of lethality/vulnerability and collateral effects codes. The goal is for the STMG to read target files in BRL-CAD, TMG, and AutoCAD (DXF) formats. Targets created by the STMG could be output in BRL-CAD, TMG, and VRML formats. The STMG will allow rapid generation and editing of target data. Structural connections including plumbing, venting, and pipes will be represented. The unique feature of the STMG will be it's ability to contain a superset of target data that can provide as much or as little target detail required by the weapon effects code. The STMG development effort is expected to be completed by the third quarter of fiscal year 2001.

Target Interaction

The Target Interaction module reads BRL-CAD and TMG targets. It provides a graphical display of the target using a bit volume approach to represent components. A bit volume is an array of bits, with each bit representing a volume of space organized on a regular grid. The bit volume approach allows MEVA-GF to model target damage as a function of time. The Target Interaction module accepts target interrogation requests (e.g. ray trace, volume intersection with a sphere or box) from the weapon effects modules (i.e. penetration, blast, fragmentation) and returns the dynamic state of the target geometry at the time requested.

Weapon Definition

The Weapon Definition module allows the user to describe the munition in terms of its geometry and material properties. These parameters include the weapon diameter, length, weight, nose shape, case thickness, and amount of explosive. The user may chose to input the weapon's center of gravity or have it calculated by the program. An arena data file containing the fragment distribution profile may also be associated with the weapon. Although multiple unique

weapon configurations may be defined, only those weapons specified in the delivery module will be used in the analysis.

Weapon Delivery

There are four delivery modules available in the MEVA-GF module library. The Bivariate Elliptical Delivery module is designed to model delivery of a guided weapon. All uncertainty in impact conditions is given in terms of standard deviations about the mean impact conditions. The Laser-Guided Delivery module is identical to the Bivariate Elliptical Delivery module except uncertainty in aimpoint is given in terms of circular error probable (CEP). The Stickbomb Delivery module takes input from the PC-based Joint Technical Coordinating Group's (JTCG) Stickbomb code[3] to model the delivery of unguided weapons. The PkCell Delivery module defines a rectangular region on the impact plane in which the impact locations will be uniformly distributed. All four of the delivery modules allow the user to define mean values for the aimpoint location (in three dimensions), trajectory angle, angle-of-attack, impact velocity, and azimuth angle. A normal distribution is assumed to model the random behavior of the impact conditions. In the Laser-Guided Delivery module, the user may also provide inputs to model a correlated delivery scenario. The guided-weapon delivery modules and the PkCell delivery module allow the user to specify multi-weapon multi-sortie attacks. The user can define unique impact conditions for each sortie, and all weapons within a sortie are assumed to follow those impact conditions.

Penetration

Two penetration modules are provided in MEVA-GF for modeling the penetration of a weapon into a hardened structure. Each penetration model is based on algorithms that are of differing degrees of fidelity.

The SAMPLL Regression methodology is a quick-running penetration analysis that models changes in angle-of-attack and weapon trajectory in a piece-wise linear mode. It applies regression equations developed from over 8000 Simplified Analytical Model of Penetration with Lateral Loading (SAMPLL)[4] calculations to model penetration through concrete. When a weapon impacts a concrete component, changes are made to the weapon trajectory and angle-of-attack, and checks are made to see if the weapon will ricochet or fail. These changes are made for concrete impacts only; the algorithms assume that the weapon takes a straight path through soil or air components. The SAMPLL Regression methodology is appropriate for use in stochastic calculations in which the run-time must be as short as possible and detailed penetration path information is generally not required.

The Curvilinear Penetration methodology applies a cavity expansion loading model and newtonian integration scheme to provide a detailed time-marching penetration analysis. This approach divides the exterior surface of the weapon into rectangular elements. Loads imparted onto the weapon by the target are calculated from stress on each surface element for each time step during the penetration process. Loads on each differential area of the weapon are determined from algorithms based on concrete and soil cavity models developed by Luk and Forrestal[5,6]. Weapon survivability is empirically determined based on internal weapon stresses. The Curvilinear Penetration modules are intended to perform detailed three-dimensional rigid body penetration analyses into three-dimensional targets composed of concrete, reinforcing bars, soil, air, and steel plate target components.

Figure 2 shows the penetration path through a 4 story underground bunker as calculated by the Curvilinear Penetration module.

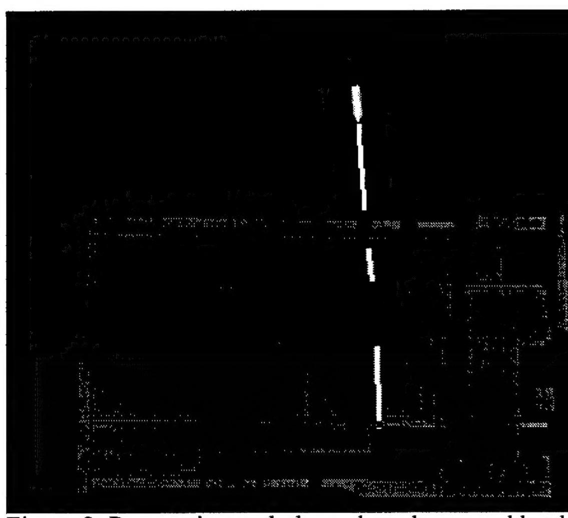

Figure 2. Penetration path through underground bunker.

Recent efforts to improve the Curvilinear Penetration methodology include the modeling of new penetrator weapons with non-traditional nose shapes. These new weapon systems are often designed with precision guidance systems for attacking fixed point targets with great accuracy. The accuracy of such weapon systems allows multiple weapons to attack a hardened target using the same aimpoint. Penetration through pre-damaged targets is a complex problem. A Multi-Hit (Layer Burst) module[7] was recently developed as a first attempt at modeling the penetration of precision guided munitions through pre-damaged targets. Further work is

required to accurately model the effects of penetration through a damaged zone near the edge of a crater.

Blast

The Airblast methodology uses a simple peak-overpressure space marching methodology to determine if structural components are damaged. A grid-based propagation algorithm is used to model airblast propagation through a target. A fixed, three-dimensional grid of cells is placed around the detonation location. The blast is measured at the centroid of each cell starting with the cells nearest to the burst point and stepping outward in all directions until a target component is encountered. When a component is found, it is evaluated to see if it survived the blast. If the component fails, the airblast propagation will continue through the breached component. Structural component failure is modeled in terms of partial damage, spall, and breach holes.

Figure 3 shows the damage calculated by the Grid Airblast module for a 1500 lb penetrator weapon detonating inside a 4 story underground bunker.

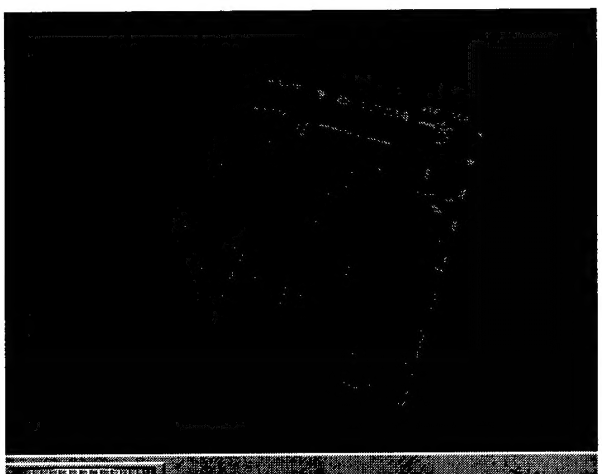

Figure 3. Blast damage predicted for 1500 lb penetrator.

The response of target components to detonation in soil is based on empirically derived curves. Damage is specified in terms of wall breach and spall zones, surface craters, and cavity expansion. Damage produced by detonation in concrete is also empirically based and is a function of the slab thickness. For a thick slab, a spall zone is formed and a debris plug falls into the room below. However, no blast pressure is propagated into the room below. For a thin slab, panel breach occurs and debris falls into the room below. Airblast pressure is also propagated into the room below.

Secondary Effects (Collapse)

Above-ground buildings are vulnerable to damage from the secondary effect of building collapse due to the removal of structural components. The Load Transmission methodology models building collapse using a component-by-component assessment of one and two-dimensional capacities. This stepped static approach is based on the local force balance. Collapse is determined by the re-evaluation of the load paths after the removal of target components. For vertical components, the load on the components is divided by the cross-sectional area and compared to compressive strength to determine whether failure occurs. For horizontal components, the total gravity load is distributed across the face or length of the component. Failure is based solely on design capacities. The collapse analysis works only with buildings constructed with the Target Model Generator.

Fragmentation

MEVA-Ground Fixed currently has only one weapon fragmentation methodology. This fragmentation effects methodology explicitly models fragment flyout and penetration from a weapon detonation. It models fragmentation effects by shooting all fragments identified in the weapon's arena data file. Included in each fragment trajectory are the effects of gravity, drag, ricochet off of ground and building surfaces and penetration through target components. After all of the fragment trajectories are calculated, they are checked for intersections with ground surfaces, building surfaces, and critical components. Ricochet and penetration are checked when intersections with ground and structural components are found. The fragmentation routine used in MEVA-GF is a space marching methodology.

Mission Evaluation

The Mission Evaluation module in MEVA-GF provides a metric for evaluating the effectiveness of a mission. The module computes the mission status based on the user selected kill criteria and the target status. There are three types of mission evaluation available through this module: Mission (Functional) Kill, K (Total) Kill, and JTCG Kill. For a Mission (Functional) Kill, components along a critical path must be killed to kill the target. This implies that the target can no longer perform its critical mission.

MEVA-GF allows the user to model target functionality using a Boolean fault tree logic. A Boolean fault tree is constructed of nodes connected in series or parallel. These nodes represent key functions of the target such

as power generation, communications, computing, heating, ventilation, air conditioning, and operations. The critical components that make up these individual functions (i.e. generators, power lines, etc.) are also represented in the fault tree. This Boolean fault tree is built within the System Definition module. The System Definition Module works in conjunction with the Mission Evaluation module for determining a Mission (Functional) Kill.

All components must be killed for a K (Total) Kill. The JTCG Kill combines Mission (Functional) Kill, K (Total) Kill, and Structural Volume Kill. For a Structural Volume Kill, 50% of structural components must be killed. The Mission Evaluation module outputs a variety of statistics to summarize a stochastic calculation. The mission statistics include the probability of target kill, the percentage of weapons delivered, the percentage of weapon failures, and the percentage of critical components killed.

MEVA-CP

The extensibility of the MEVA-GF architecture allows the user to create unique networks for assessing special cases. The proliferation of nuclear, biological, and chemical (NBC) weapons is of great concern to the Department of Defense. Confronting adversaries who possess these Weapons of Mass Destruction (WMD) requires careful consideration and planning. It is important to be able to accurately predict the effectiveness of attacking WMD production, transfer, and storage facilities. Understanding these effects is critical to the development of air-to-surface munitions to be used against WMD targets. The development of the Agent Release Model (ARM)[8] addresses the need for predicting the amount, form and timing of agent released from containment vessels due to impact by conventional or agent defeat weapon systems. ARM calculates both percent of agent aerosolized and percentage of agent spilled as a function of time. Figure 4 is an example ARM prediction depicting the percentage of agent aerosolized.

The internal dispersion of the released agent inside a target and subsequent external venting to the atmosphere is predicted by the Multi-chamber Blowdown Model (MBLM)[9]. The Agent Release Model and the Multi-chamber Blowdown Model are both being integrated into the MEVA-GF framework to assess the potential for the release and dispersion of chemical and biological agents from counterproliferation (CP) targets. The integration of ARM and MBLM into MEVA-GF (coined MEVA-CP) provides a capability for modeling the entire event from weapon delivery to agent dispersion into the atmosphere.

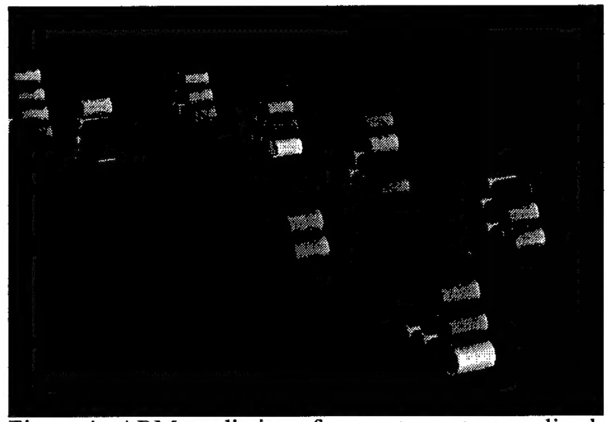

Figure 4. ARM prediction of percent agent aerosolized.

CONCLUSION

The Modular Effectiveness Vulnerability Assessment – Ground Fixed (MEVA-GF) is an engineering tool for assessing the vulnerability of fixed ground targets to conventional weapon attack. MEVA-GF's extensible framework allows separately compiled methodologies to be linked to form an assessment network. These methodologies need not be limited to the ground fixed target set. Engineering models that are appropriate for ground mobile/relocatable targets or air targets could conceivably be linked to form MEVA-Ground Mobile or MEVA Air-to-Air assessment networks. The development of the MEVA-Counterproliferation network for assessing WMD targets is an example of the potential for leveraging existing assessment methodology to provide a unique modeling capability.

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